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AGARD REPORT No.720

Problems of System Identification in Flight Vibration Testing

NORTH ATLANTIC TREATY ORGANIZATION

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ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT

(ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD)

AGARD Report No.720

PROBLEMS OF SYSTEM IDENTIFICATION IN FLIGHT VIBRATION TESTING

by

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Paper presented at the 5th Meeting of the Structures and Materials Panel held in Vimeiro, Portugal on 9–14 October 1983.

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Published April 1984

ISBN 92-835-1470-X

Printed by Specialised Printing Services Limited
40 Chigwell Lane, Loughton, Essex IG10 3TZ

PREFACE

At the Fall 1983 Meeting of the AGARD Structures and Materials Panel (SMP) in Vimeiro (Torres Vedras) Portugal, Mr K.König of MBB-Bremen presented the enclosed paper, "Problems of System Identification in Flight Vibration Testing". He expressed the opinion that the existing computational methods for modal analysis of flight vibration data and flight flutter may be quite unreliable, unless great care is exercised in their use. He examined the data from recent flight tests of the Airbus A310 and considered the errors that might be sensitive to the digitization process; the correlation length; the excitation signal; "off-set" corrections; the number of modes analyzed; transfer functions of deformations, velocities or accelerations; aircraft symmetry; transducer location and external disturbances.

He concluded that the state-of-the-art of flight vibration testing is poor and proposed that the AGARD/SMP formulate a "Mobility Experiment" for data analysis by existing and newly developed European and North American methods.

The Sub-Committee on Aeroelasticity is considering such an experiment in planning its future activities for the AGARD/SMP.

James J.OLSEN
Chairman, Sub-Committee
on Aeroelasticity

CONTENTS

PROBLEMS OF SYSTEM IDENTIFICATION IN FLIGHT VIBRATION TESTING

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SUMMARY

The accuracy of modal data analysis was studied for two tests with up to 8 different methods of analysis.* It was found that the state of the art is poor and insufficient to deal with critical flutter cases. Improvements are possible and should be sponsored.

1. INTRODUCTION

The intention of the following paper is to show the state of the art of system identification in flight vibration tests (FVT). The state of the art is poor as one will see. Yet it appears that examples about this subject are rare in publications. So the following is no scientific report but a summary of some experience recently gathered.

One of the purposes of a FVT is to "measure" via system identification the modal data of the flying a/c and to show the influence of flight conditions on such data. Modal damping is used as a direct measure of the safety margin of the tested a/c against flutter.

However, all "measured" modal data such as eigenfrequencies, damping and residues (or modal deformations) should be compared with the predicted modal data to show that they correspond to one another and thus to demonstrate that a reliable extrapolation up to the required but not flyable 1.2 V_D is possible on a purely theoretical basis.

For this, one must assume that the "measured" data are reliable or that their scatter is sufficiently small. This, then, is the crux of the matter, because if the accuracy of the measured data is insufficient a too pessimistic extrapolation may ensue as a result of which a/c capacity might be wasted. The question is whether this is unavoidable or whether this should be a challenge to the engineers for improvement.

2. FLIGHT VIBRATION TESTS ON THE AIRBUS

The following examples are taken from FVT on the Airbus A31o, the new European airliner.

Fig. 2-1 shows some of its test installations. Here the excitation was induced by two little vanes at each wing tip and by bonkers at the tail. The vanes were moved with a so-called frequency sweep. A detailed description of the vane is given in ref. 1.

Accelerometers as pick-ups were installed at all extreme positions of the a/c, at all movable points and at symmetrical locations. Typical measured signals are shown in fig. 2-2. One can see that the frequency of excitation initially increases from 1.4 to 5.6 Hz and then decreases to 1.4 Hz. The amplitude of the vane angle is constant and the amplitude of the lift force of the vane is also about constant. The shown response is from the wing in z direction and from the engine in z and y direction. As expected, the signal is large at the wing tip. The smallest response was found at the engine in z direction. The different signals reflect the resonances at different frequencies.

The next step required in system identification is to extract from such measurements transfer functions. They contain the complete information on modal data of the system if linear as may be assumed.

No power spectra of the response are shown here. They contain less information and therefore are of minor interest for the following.

Fig. 2-3 shows transfer functions from the right tip vane lift force to the accelerations of wing tip, horizontal tail, front fuselage, and engine (lateral and vertical).

All functions belong to one single test. Their magnitude is very different for the different locations but a modal analysis was possible for all of them. To obtain a quick answer after each flight, the whole work of analysis was shared by up to three different teams, each team using its own equipment consisting of two black boxes called modal analysers (from Hewlett Packard and Nicolet Scientific Corp.). Moreover, a simple method developed by the author himself for use on any modern computer (details s. ref. 2.) was applied.

Fig. 2-4 shows a typical result. One can see the smooth curves of the frequencies of the different modes versus a/c speed. Practically no scatter is evident and any critical frequency crossing may be far outside of the flight envelope. These analysis results were so good that it was possible to detect the transonic influence of the Mach-number on the modal frequencies as is shown in fig. 2-5. One can see how the frequencies of the two critical modes of wing bending and engine pitch (z) approach one another at 0.78 to 0.84 Ma-number.

* The author wishes to express his thanks to all who contributed to the work of analysis. Further he must mention especially the activities of ONERA who contributed much to the design philosophy of the tip vane system and delivered the hydraulic motor, the control box and one of the safety boxes of this system which was used as a very effective exciter during FVT.

The damping shown in fig. 2-4 was found to be not so good and some scatter was apparent. Nevertheless the drawn curves indicate clearly the increasing tendency with increasing a/c speed, thereby demonstrating that the a/c has a reasonable safety margin against flutter.

3. THE POINT IN QUESTION

What stands behind such pictures as shown above? How accurate are the modal data? To obtain some information about this, an interesting study was carried out in preparation of the A310 FVT. From one single well prepared test with the Airbus A300 (details see ref. 1), the measured signals from a good response point were given to 7 different persons in 4 European countries for modal analysis. The analyses were carried out with 8 different methods, including 3 with hardware analysers as available on the market (two as detailed above, the third from GenRad Inc.). Another 4 of the 8 methods are well known from European publications and the last method is the one mentioned in ref. 2.

The analysed transfer function can be seen in fig. 3-1. The function looks rather smooth but it contains some disturbances. So it was a good example for comparing the efficiency of the different methods. Table 3-1 gives all modal data found. Unfortunately the truth, that is the "true" modal data of the tested a/c are not known and cannot be established by the nature of the matter. Therefore, a direct evaluation of the different methods of analysis is not possible, it only being possible to try to draw conclusions by comparison between the more or less accurate modal date. A further point to be noted is that one of the 8 methods was a single mode analysis. One other method used additional transfer functions from other pick-ups. Three methods used not only the same measured signals but also the same transfer function derived from the signals as indicated in the table. The final results of this study were very disappointing. A large scatter of up to 5% of mean frequency and 45% of mean damping was found. It is remarkable that the scatter is large for all modes, and a scatter of up to 16% was established for damping even in the very distinctive 5th mode with its large resonance peak.

Furthermore, it is apparent that no two of the eight methods give similar results for all modes. Even if some of the frequencies or the dampings are similar, the one or other value differs considerably. So ultimately one has to learn that the reliability of (at least some of) the up-to-date methods of modal analysis is very poor and that the scatter of damping is ten times higher than the scatter of frequencies. But if the measured damping constituing the crucial safety margin against flutter has only an accuracy of about 4o% or more, does not that mean a larger safety margin would be needed for the operation of the a/c during the FVT's? To find an answer to this question, it seems to be worthwhile to study the sources and the nature of the scatter in more detail. Some examples of this are given below.

4. EXAMPLES

In a systematic study a single test from the Airbus A31o test program was analysed by the modal analysis method of ref. 2, which was of cource best known and accessible to the author.

Reference is made to the Airbus but this study is not intended to constitute a detailed analysis of this aircraft. On the contrary, the examples are chosen in such a way that they allow general conclusions which may be important and useful for other aircraft.

The different possibilities arising from the handling of the analysis method itself will be studied first and the influence of external disturbances such as air turbulence or others shown at the end.

All analyses were carried out under the same conditions so that they can be compared directly with one another. But it should be made clear that it is not allowed simply to add the different values of scatter of the modal data found in the different studied examples.

4.1 Digitisation

The first error may be introduced during digitisation of the analog test signals even if a reasonable low pass filter for antialiasing has been used.

Figs. 4.1-1, -2 and -3 show the transfer function (s. also fig. 2-3) from right tip vane lift force to right tip acceleration and the approximations for different sampling rates. The Fast Fourier Transformation necessary for the computation of the "measured" transfer function was always accomplished in one step for the whole excitation period of 2 minutes. No overlapping or zero completion was used. Only the time step and therefore the total number of points were varied. The first two transfer functions and their approximation look very good, but the third function, which should allow analysis up to 3.9 Hz due to its sampling rate, is already rather disturbed and should not be used further. Table 4.1-1 gives a comparison of the modal data found. The difference between the two better sets of results reaches up to 1% for frequencies, up to 24% for damping and up to 43% for residues.

4.2 Correlation Length

A Hamming filter was used in all analyses for noise reduction. The sharpness of this filter was varied between 15% and 1oo% of the available length of the time signal of the Fourier transformed transfer function.

In fig. 4.1-1, 3o% was used. Fig. 4.2-1 shows for comparison the large transfer function of wing acceleration with 1oo% correlation length. In fig. 4.2-2 and -3 the same is given for the tiny transfer function (compare fig. 2-3) from the right tip vane lift force to right engine vertical acceleration. There the disturbance is much larger but fortunately outside the frequency range that is of interest. Fig. 4.2-4 summarises all resulting modal frequencies and dampings, showing these plotted versus the correlation length. It is apparent that the frequencies are hardly influenced, whereas some dampings are highly dependent on the correlation length. Yet it seems that even most of the damping values converge with increasing length. So one can expect that the influence of the Hamming filter on frequency and damping is not so critical if the transfer function shows clear resonance peaks and if a reasonably large correlation length is used. For later comparison table 4.2-1 shows the deviations of modal data which arise from the use of 3o% correlation length instead of 1oo% length. The deviations reach up to 1% for frequencies, up to 8o% for damping and up to 214% for residues. The residues are obviously the most sensitive modal data. Therefore they will not be included in further studies so as to concentrate on the more important points.

The coherence functions shown as dotted lines in most figures of transferfunctions indicate the amount of noise which has been eleminated from these transferfunctions by the filtering process. But it should be mentioned that this does not guarantee that no additional disturbances are hidden in the transferfunctions (compare for example Fig. 4.2-1 and 4.1-1).

4.3 Selected Excitation Signal

If more than one exciter is used at the same time for excitation of a system, the time signal of these exciters should be equal up to a constant factor. To check this basic requirement, a transferfuntion from the right to left lift force of the vanes was built up as shown in fig. 4.3-1. The phase changes by up to 4 degrees and the magnitude by up to 7% within the frequency range that is of interest. This is not very much and it should not make much difference whether one uses the right or the left lift force or even the sum of both as the reference to build up the transferfunction to the different acceleration pick-ups.

For comparison, fig. 4.3-2 shows these transfer functions to the right wing tip acceleration. They look rather similar up to a small factor. The results of the modal analysis of the function with reference to the right lift force are already shown in fig. 4.1-1. Fig. 4.3-3 shows the comparable results for the transfer function with reference to the left lift force. The differences for most of the modes are not so large, but one mode reveals negative damping. This is a possible mathematical solution of the approximation program which produces the best correspondence as is evident yet this solution is impossible for physical reasons and indicates that there must be a disturbance within the signals or an external excitation. It is remarkable that this effect appears at the third mode which is antisymmetric. Such a mode should not be visible with the applied symmetrical excitation and its resonance peak is in fact rather tiny. Hence it is clear that such modes will reflect any disturbances first. Therefore it was next tried to make the analysis only for the two modes in this resonance range. The result is given in figs. 4.3-4 and -5 but it does not show a good correspondence. The chosen frequency band is too large to analyse only two modes with a good accuracy.

Next the frequency band was reduced and a reasonable analysis was possible as figs. 4.3-6 and -7 show. In fig. 4.3-8 the transfer function relating to the sum of the left and right tip vane lift force was used. A comparison of all results is given in table 4.3-1. The maximum scatter reaches up to 3% for the frequencies and up to 39% for damping.

4.4 "Off-Set" Correction

The applied method of analysis provides the approximation of the transfer function with the smallest square error. For compensation of the influence of modes which do not have their resonance peak within the analysed frequency range, an "off-set" correction is possible. This adds iteratively chosen values to the real and imaginary part of the transfer function which varys linearly with the frequency.

In fig. 4.1-1 the analysis was carried out with 5 iterations. The off-set correction found is shown in fig. 4.4-1 by the interrupted line showing the used frequency axis for the real and imaginary parts of the transfer function. In figs. 4.4-2, -3 and -4 the analysis results are given for 3, for 1 and for 0 iterations. The correspondence of the first 3 modes is rather good for all 4 examples, meaning that there is not much influence from other modes in this frequency range. However the modes which were each analysed separately showed a poor correspondence if no off-set correction was applied. When these modes are analysed within one step (s. fig. 4-4), but still without off-set correction, the correspondence looks much better which means that these three modes mainly disturb each other.

A comparison of all the modal data found is given in table 4.4-1 showing that the maximum scatter reaches up to 1% for the frequencies and up to 24% for damping.

4.5 Number of Modes Analyzed

The number of modes to be analyzed must be given as an input to the computer program.

Fig. 4.5-1 shows what happens if one tries to analyse the transfer function of fig. 4.1-1 in the whole frequency range and for 5 modes. The curves do not correspond very well with one another and an increase or a reduction of the number of modes does not help. On the contrary, it makes the situation worse, whereas the approximation shown in fig. 4.1-1 appears much more reliable.

Hence, one may conclude that better results are found if the analysis is only performed in the frequency range in the direct vicinity of resonance peaks and with the appropriate number of modes. An example of an analysis of the peaks at about 2 Hz with 2 modes has already been shown in fig. 4.3-4. The correspondence was rather poor,but was found to be better when the analysis was performed for only one mode, as can be seen in fig. 4.5-2. Nevertheless the most accurate modal values are to be expected when this range is analyzed for 3 modes. A similar situation was found for the modes with higher frequencies. The approximation as shown in fig. 4.5-3 should be best. There one can see the solid line representing the given transfer function, the crosses representing the approximation by the polynomial coefficients including off-set correction as usual in all the other pictures, and the dotted line the approximation by the modal data found including the residues but excluding the off-set correction. So one can see that some influence from higher modes is effective in the second part of the analysed frequency range.

A summary of all results is given in table 4.5-1. It is evident that the scatter of data is rather large reaching up to 1% for the frequencies but up to 71% for damping.

4.6 Acceleration or Deformation

The transfer functions shown up to here were always the functions of the accelerations which were measured. They were not the basis for the approximations. The computer program normally uses the transfer functions of deformation as the basis for approximation. These functions of deformation are computed from the functions of acceleration by division by the negative square of the circular frequencies and the given residues belong to the deformation. Fig. 4.6-1 shows the transfer function of deformation belonging to fig. 4.1-1. Both curves look rather different and so one can imagine that one might obtain different results if the function of acceleration were used as the basis for approximations. This is possible by minor modifications of the computer program. Fig. 4.6-2 gives the result. The correspondence looks rather similar to that of fig. 4.1-1 but the found modal data do differ.

As an additional example fig. 4.6-3 gives the result of the analysed acceleration from the more disturbed transfer function of engine pitch. This may be compared with fig. 4.2-2 where the deformation was the basis for approximation.

Table 4.6-1 summarises the resulting modal data and gives the mean values from acceleration and deformation. The scatter reaches 2% for the frequencies and 9% for damping. Yet it cannot be determined whether the results from the transfer function of acceleration or of deformation are more reliable. So perhaps one should use the mean values as the final result.

4.7 Aircraft Symmetry

A further point of interest is the question of symmetry of the tested a/c. Normally it should be rather symmetrical.

Fig. 4.7-1 shows the comparison of the transfer functions from the right and left wing. They are a bit different. Therefore it may not be astonishing after all that the modal analysis of the left wing, as shown in fig. 4.7-2, gives different results in comparison to the right wing (s. 4.1-1). The second example is taken from engine pitch with its small and more disturbed transfer functions. Fig. 4.7-3 shows the comparison. Here larger deviations between the right and left are evident. Nevertheless the modal analyses (right see 4.2-2 and left see fig. 4.7-4) do not yield excessive differences for the modal data. This should indicate that the found differences of the transfer functions result from the asymmetry of the flying a/c and not from disturbances. The comparison of all data is given in table 4.7-1, where the maximum scatter reached is 1% for the frequencies and 58% for damping.

If, however, antisymmetric modes a wz and aE which are not optimally excited are left out of consideration, the maximum scatter of the damping may be reduced to 7%.

4.8 Pick up Location

Transfer functions and analysis results from wing tip and engine pitch were already shown in fig. 4.1-1, 4.2-2, 4.7-2, 4.7-4. Fig. 4.8-1 gives additional information for engine lateral movement, fig. 4.8-2 for the front fuselage and fig. 4.8-3 for the tip of the right horizontal tail. The correspondence of the curves of all approximations looks rather good. The frequencies and dampings found are given in table 4.8-1.

The first column of this table shows to which mode the data belong, and where the largest modal deformation is to be expected. The excitation was symmetrical but nevertheless two antisymmetric modes were found. There are three reasons for this as already mentioned: an inexact symmetrical excitation, a certain asymmetry in the modes and some air turbulence. Most of the other modes were found in more than one pick up as expected. The scatter due to the different locations of these pick ups reaches up to 2% for the frequencies and up to 58% (or 38% if the not optimally excited modes aW2 and aE2 are left out of consideration) for the damping. These are substantial figures, greater than is desirable. But it should be noted that some scatter may be caused by pick-ups which are not optimally placed with respect to maximum modal deformation. Therefore, the question arises: which result is more reliable - the one from the optimum location (underlined in the table) with the distinct signals and the large transfer functions - or the mean values determined by a larger number of values from small transfer functions. Moreover, this leads to the more general question whether in principle the reliability of the modal data of one mode may be improved by including a larger number of pick-up signals into the analysis. Perhaps, if the additional information is less reliable, the additional effort of including this information is set off by the required elimination of its uncertainty.

4.9 External disturbances

As already mentioned the studied flight may have been disturbed by external sources, perhaps by some light air turbulences. A further indication for this is apparent on comparison of fig. 4.9-3 and 4.9-4. There it is shown what happens if only the first or the second half of the full up and down sweep is analysed. Both cases should give the same results because the full frequency range is covered each time (compare also chapter 4.1). However the scatter, as given in table 4.9-1, is very large reaching up to 3% for the frequencies and up to 160% (or 129% if mode aW2 is again left out of consideration) for damping. The damping values of the first two modes are especially remarkable. A larger value appears once in the first and once in the second mode.

Figs. 4.9-1 and -2 show the time signals of excitation and response which belong to these analyses. It is difficult to see any disturbance at a first glance. The reduction of excitation amplitude at higher frequencies results from the efficiency of the tip vane and does not give much indication of the disturbance. The response is rather symmetrical in time and amplitude but not exact. The smaller asymmetry in time results from the up and down sweep itself which causes different initial conditions at up and down resonance crossings. Nevertheless the amplitudes should be symmetrical. Yet it is evident that the second half of the entire excitation period is less symmetrical than first half so that one might perhaps conclude that the results of the analysis of the first half of the complete sweep are more reliable. Furthermore, this would be in line with the coincidence of the "measured" and approximated transfer functions which is much better in fig. 4.9-3 than in 4.9-4, especially for the first three modes.

4.1o Accuracy Reached

Finally the best data found in the analyses described above are to be compared with the results of two other analyses carried out by different persons with the modal analysers from Hewlett Packard and Nicolet Scientific Corp. already mentioned earlier. A comparison of the different transfer functions used is shown in fig. 4.1o-1 for wing acceleration and in fig. 4.1o-2 for engine vertical acceleration. The functions of the three different methods of analysis differ and different modal data are to be expected in view of the details given above.

Table 4.1o-1 gives all the data together with the information already mentioned. A final scatter of values of up to 2% for frequencies and up to 35% for damping is reached even in careful analyses.

5. CONCLUSIONS

The state of the art of system identification in FVT is poor. The accuracy of the various modal data which result differs reaching a few percent for eigenfrequencies, several 1o% for the modal damping and several 1oo% for the residues. Table 5.1 gives a survey summarising the data found for the studied examples.

Of course it would be possible to reduce the amount of scatter by optimisation of location of pick-up and excitation, by leaving out modal data from pick ups which give only a small response due to these modes, by adjustment of filtering, and especially by increasing the duration of the test, or by repetition of the test at different flights in calm. But this requires a large amount of time and money and the question remains whether the reached accuracy is sufficient or whether there are other possibilities for an improvement of the analysis methods. They would be of particular importance if an a/c or a model in the wind tunnel were to be flown up to its flutter boundary; or if a so called "hump shape" of damping curve were predicted where the damping theoretically reduces with increasing speed up to a very small but positive level and increases again beyond of this minimum. If a certain amount of uncertainty has to be accepted and if one dares to use a linear extrapolation, a reasonable safety margin would very soon call for a stop of further tests as may be seen from fig. 5-1. If, for example, the modal

damping from one test step to the next is found to be constant, and if 5o% scatter is realistic, the next step width must be smaller than one half of the last step width. No hump of damping curve could be passed by such a procedure and perhaps a lot of the a/c's capacity would have to be given away only due to the lack of knowledge.

For the improvement of the analysis methods the following steps could be recommended:

- To list all existing methods
- To acquire more detailed information about other available analysis methods and their sensitivity to disturbed input signals
- To compare different analysis results not only with one another but with the truth. Yet the "truth" must in itself be reliable and hidden in signals which have been disturbed in a known and realistic way
- To look for alterations of the analysis methods
  An improvement might be reached by combining different methods, and if not already available by maximum likelihood weighting, by including symmetrical pick-ups at significant locations or by using different definitions of the optimum which is approximated.

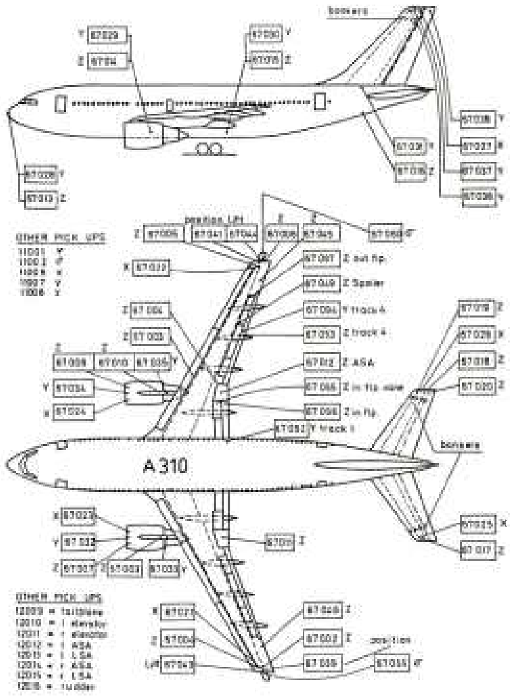


FIG. 2-1 FVT PICK UP INSTALLATION

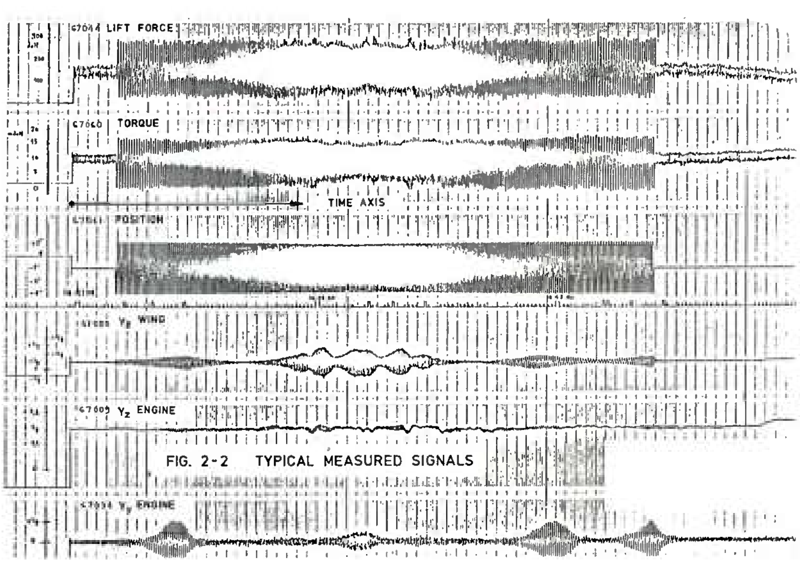


FIG. 2-2 TYPICAL MEASURED SIGNALS

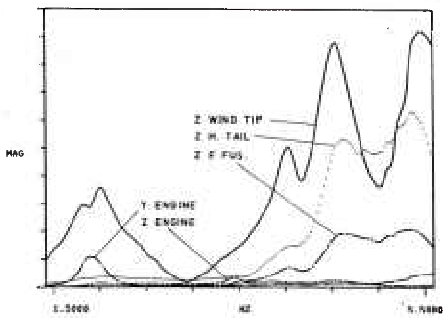


FIG. 2-3 TRANSFER FUNCTIONS OF A-310

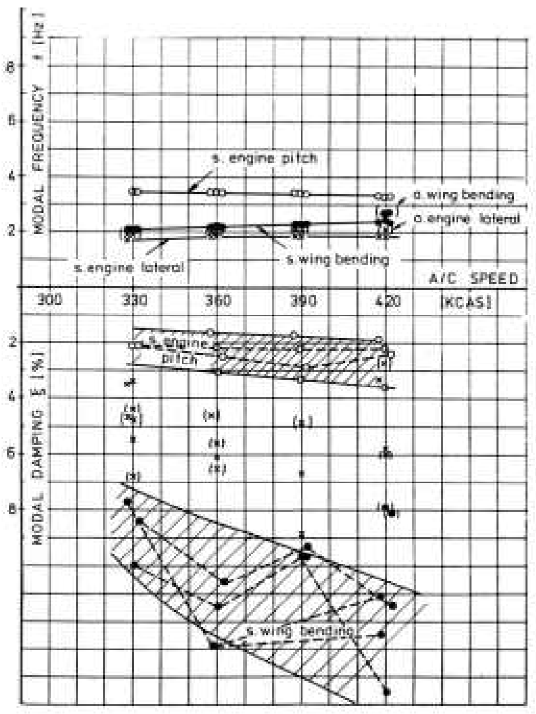


FIG. 2-4 A-310 FVT RESULTS
Influence of A/C speed on modal data at
Ma = 0.78

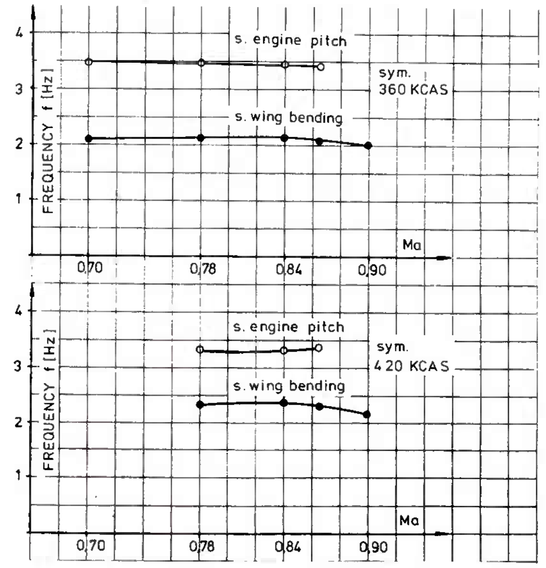


FIG. 2-5 A-310 FLIGHT VIBRATION TEST RESULTS
Influence of Ma-number on s. engine pitch
and s. wing bending modes

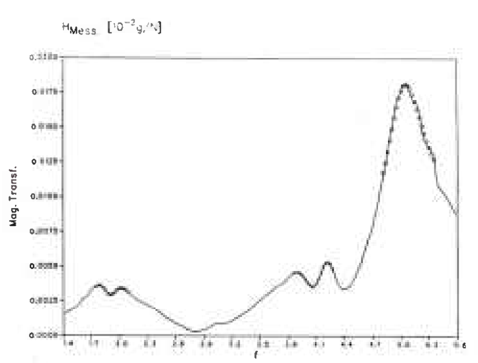
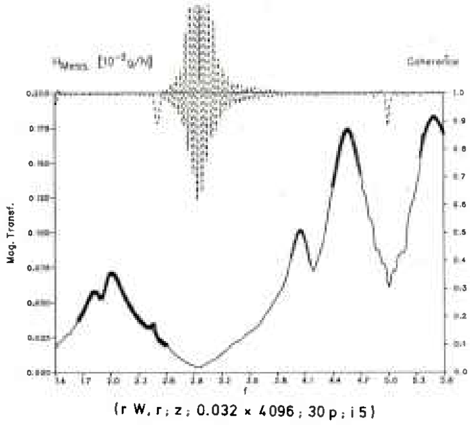


FIG. 3-1 TRANSFER FUNCTION OF ONE TEST WHICH
WAS ANALYSED BY 8 DIFFERENT METHODS

METHOD	1	2	3	4	5	6	7	8	MEAN	ST DEV.	SCATTER % OF MEAN -/+
SAME TR.F. USED	X					X		X			
FREQU.(HZ)	1.75	1.88	1.79	1.84	1.84	1.84	1.75	1.82	1.81	0.04	3/4
DAMP..(%))	6.2	5.8	7.3	11.2	10.7	8.9	10.	7.0	8.4	2.0	31/33
2.MODE	2.08	1.95	2.04	1.97	1.93	1.96	1.99	1.98	1.99	0.05	3/5
	7.2	10.8	5.0	4.3	4.5	6.8	5.	7.7	6.4	2.1	33/31
3.MODE	3.89	3.98	3.94	3.99	3.87	3.95		3.95	3.94	0.04	2/1
	2.9	4.2	4.9	3.9	4.3	2.9		4.7	4.0	0.7	27/18
4.MODE	4.24	4.22	4.24	4.23	4.24	4.29		4.20	4.24	0.02	1/1
	1.2	2.6	1.9	2.5	1.6	2.6		2.7	2.2	0.5	45/23
5.MODE	5.01	5.00	5.03	5.01	5.00	5.01	5.07	5.04	5.02	0.02	1/1
	4.6	4.4	4.5	4.3	3.8	4.8	5.	4.2	4.5	0.3	16/11

										MAX.	5
											45

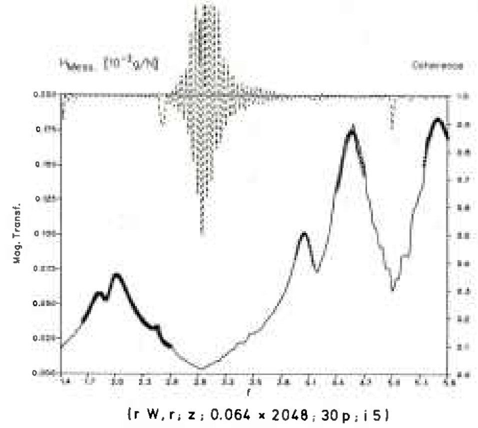
TABLE 3-1 INFLUENCE OF DIFFERENT ANALYSIS
METHODS ON MODAL DATA



(r W, r; z; 0.032 × 4096; 30 p; i 5)

Frequency Interval [Hz]		Haupt Freq. [Hz]	Damping Ratio [/]	Residuum Magn.	Phase [deg]	Mode $\lvert\phi_{yn}\cdot\phi_{xn}/M_n\rvert$ [/]
1.65	2.60	1.90	0.0490	2.82E-04	-36.6	6.89E-03
1.65	2.60	1.95	0.0807	8.04E-04	106.8	2.01E-02
1.65	2.60	2.47	0.0097	5.55E-06	0.8	1.72E-04
3.95	4.15	4.08	0.0359	1.13E-04	90.0	5.77E-03
4.40	4.70	4.56	0.0407	1.84E-04	90.0	1.05E-02
5.35	5.60	5.43	0.0550	2.98E-04	90.0	2.03E-02

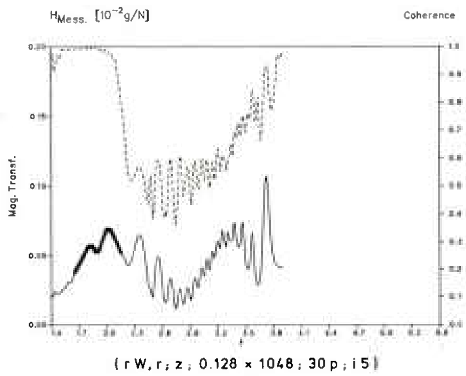
FIG. 4.1-1 TRANSFER FUNCTION OF WING TIP: ANALYSED WITH 4096 SAMPLES AND 0.032 sec SAMPLE RATE



(r W, r; z; 0.064 × 2048; 30 p; i 5)

Frequency Interval [Hz]		Haupt Freq. [Hz]	Damping Ratio [/]	Residuum Magn.	Phase [deg]	Mode $\lvert\phi_{yn}\cdot\phi_{xn}/M_n\rvert$ [/]
1.65	2.60	1.89	0.0531	3.32E-04	-15.5	8.02E-03
1.65	2.60	1.96	0.0760	7.51E-04	115.8	1.90E-02
1.65	2.60	2.47	0.0116	6.19E-06	-4.3	1.92E-04
3.95	4.15	4.08	0.0375	1.24E-04	90.0	6.37E-03
4.40	4.70	4.56	0.0396	1.75E-04	90.0	1.00E-02
5.35	5.60	5.43	0.0421	1.69E-04	90.0	1.15E-02

FIG. 4.1-2 INFLUENCE OF DIGITISATION; WING; 2048 SAMPLES; 0.064 sec SAMPLE RATE



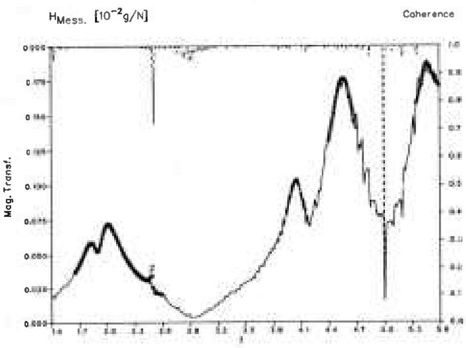
(r W, r; z; 0.128 × 1048; 30 p; i 5)

Frequency Interval [Hz]		Haupt Freq. [Hz]	Damping Ratio [/]	Residuum Magn.	Phase [deg]	Mode $\lvert\phi_{yn}\cdot\phi_{xn}/M_n\rvert$ [/]
1.65	2.15	1.87	0.0582	2.69E-04	28.3	6.16E-03
1.65	2.15	1.98	0.0711	5.11E-04	117.6	1.31E-02

FIG. 4.1-3 INFLUENCE OF DIGITISATION; WING; 1048 SAMPLES; 0.128 sec SAMPLE RATE

NO. OF SAMPLES		1024*	2048	4096	DEVIATION
TIME (MS)		128	64	32	% OF "32"
MODE:					
EY	FERQU.(HZ)	1.87	1.89	1.90	1
	DAMP. (%)	5.8	5.3	4.9	8
	RESIDUE	2.7E-4	3.3E-4	2.8E-4	18
1.WZ		1.98	1.96	1.95	1
		7.1	7.6	8.1	-6
		5.1E-4	7.5E-4	8.0E-4	-6
AWZ	* POOR,		2.47	2.47	0
	NOT INCLUDED		1.2	1.0	20
	IN DEVIATION		6.2E-6	5.6E-6	11
WX			4.08	4.08	0
			3.8	3.6	6
			1.2E-4	1.1E-4	9
FZ			4.56	4.56	0
			4.0	4.1	-2
			1.8E-4	1.8E-4	0
2.WZ			5.43	5.43	0
			4.2	5.5	-24
			1.7E-4	3.0E-4	43
				MAX.	1
					24
					43

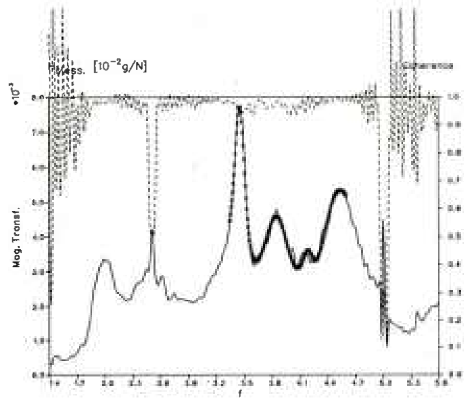
TABLE 4.1-1 INFLUENCE OF DIGITISATION
(r W, r; z; 30 p; i 5)



Frequency Interval [Hz]		Haupt Freq [Hz]	Damping Ratio [/]	Residuum Magn.	Phase [deg]	Mode $\lvert\phi_{yn}\cdot\phi_{xn}/M_n\rvert$ [/]
1.65	2.60	1.88	0.0443	2.03E-04	-11.4	4.84E-03
1.65	2.60	1.96	0.0771	6.38E-04	108.6	1.60E-02
1.65	2.60	2.49	0.0040	4.76E-06	-15.0	1.49E-04
3.95	4.15	4.07	0.0200	3.46E-05	90.0	1.77E-03
4.40	4.70	4.56	0.0348	1.42E-04	90.0	8.11E-03
5.35	5.60	5.45	0.0155	2.02E-05	90.0	1.38E-03

(r W, r; z; 0.032 × 4096; 100 p; i 5)

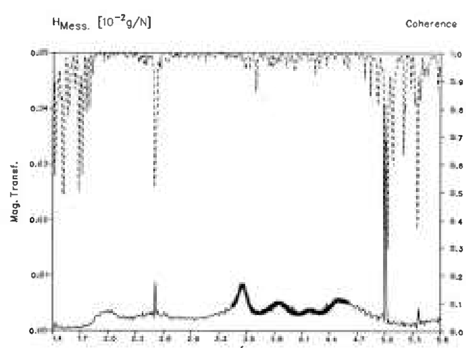
FIG. 4.2-1 INFLUENCE OF CORRELATION LENGTH; WING; 100 % LENGTH



Frequency Interval [Hz]		Haupt Freq. [Hz]	Damping Ratio [/]	Residuum Magn.	Phase [deg]	Mode $\lvert\phi_{yn}\cdot\phi_{xn}/M_n\rvert$ [/]
3.35	4.60	3.87	0.0438	1.05E-05	29.9	4.98E-04
3.35	4.60	4.46	0.0488	1.22E-05	128.6	7.01E-04
3.35	4.60	4.19	0.0194	1.99E-06	176.8	1.05E-04
3.35	4.60	3.46	0.0174	4.84E-06	83.5	2.10E-04

(r E, r; z; 0.032 × 4096; 30 p; i 5)

FIG. 4.2-2 INFLUENCE OF CORRELATION LENGTH; ENGINE, VERTICAL; 30 % LENGTH



Frequency Interval [Hz]		Haupt Freq. [Hz]	Damping Ratio [/]	Residuum Magn.	Phase [deg]	Mode $\lvert\phi_{yn}\cdot\phi_{xn}/M_n\rvert$ [/]
3.35	4.60	3.46	0.0150	4.38E-06	85.1	1.90E-04
3.35	4.60	3.86	0.0292	5.60E-06	24.2	2.69E-04
3.35	4.60	4.18	0.0214	3.61E-06	-145.5	1.88E-04
3.35	4.60	4.46	0.0247	3.34E-06	138.7	1.90E-04

(r E, r; z; 0.032 × 4096; 100 p; i 5)

FIG. 4.2-3 INFLUENCE OF CORRELATION LENGTH; ENGINE, VERTICAL; 100 % LENGTH

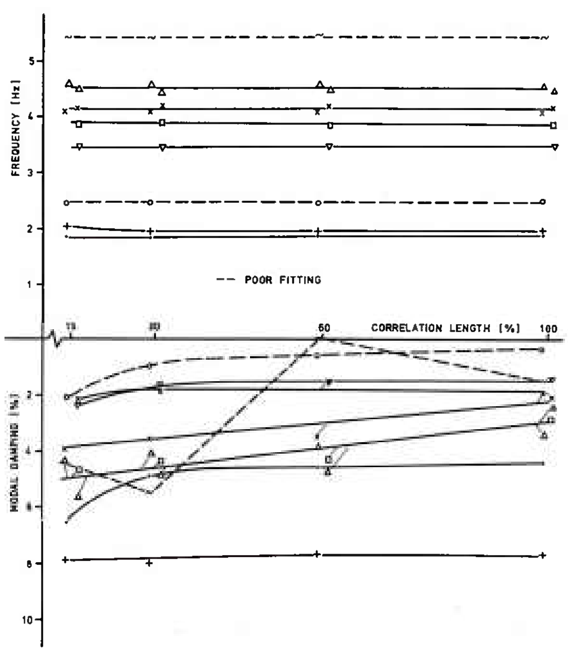


FIG. 4.2-4 INFLUENCE OF CORRELATION LENGTH ON MODAL DATA

PICK UP CORR.L.(%)		WING 30	WING 100	ENGINE 30	ENGINE 100	DEVIATION % OF "100"
MODE:						
EY	FERQU.(HZ)	1.90	1.88			1
	DAMP. (%)	4.9	4.4			9
	RESIDUE	2.8E-4	2.0E-4			40
1.WZ		1.95	1.96			-1
		8.1	7.7			5
		8.0E-4	6.4E-4			25
AWZ		2.47	2.49*			
		1.0	0.4			
		5.6E-6	4.8E-6			
EZ				3.46	3.46	0
				1.7	1.5	13
				4.8E-6	4.4E-6	9
AEZ				3.87	3.86	0
				4.4	2.9	51
				1.1E-5	5.6E-6	96
WX		4.08	4.07	4.19	4.18*	0
		3.6	2.0	1.9	2.1	80
		1.1E-4	3.5E-5	2.0E-6	3.6E-6	214
FZ		4.56	4.56	4.46	4.46	0
		4.1	3.5	4.9	2.5	17
		1.8E-4	1.4E-5	1.2E-6	3.3E-6	28
2.WZ		5.43	5.45*			
		5.5	1.6			
		3.0E-4	2.0E-5			
					MAX.	1
						80
						214

* POOR, NOT INCLUDED IN DEVIATION

(r , r ; z ; 0.032×4096 ; i5)

TABLE 4.2-1 INFLUENCE OF CORRELATION LENGTH

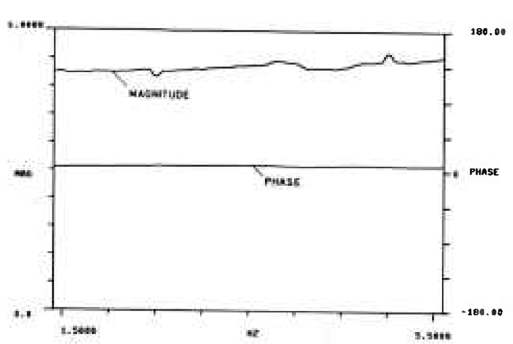


FIG. 4.3-1 TRANSFER FUNCTION : RIGHT-TO-LEFT TIP VANE LIFT FORCE

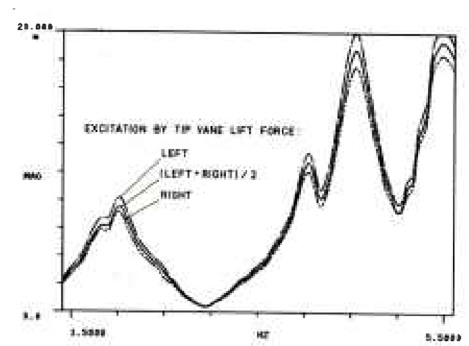
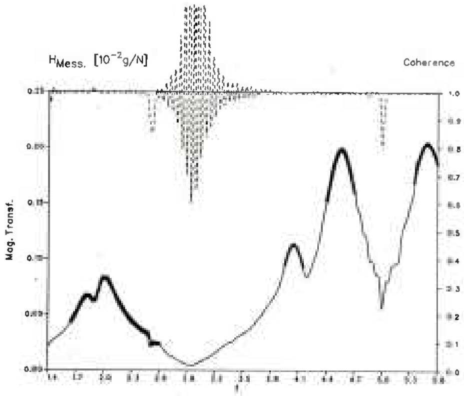


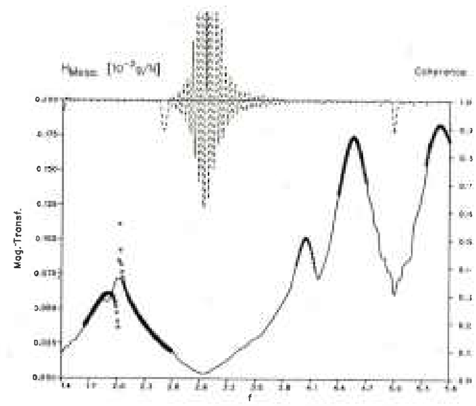
FIG. 4.3-2 TRANSFER FUNCTION : FROM DIFFERENTLY DEFINED EXCITATIONS TO ACCELERATION OF RIGHT WING TIP



(r W, l ; z ; 0.032 × 4096 ; 30 p ; i 5)

Frequency Interval [Hz]		Haupt Freq. [Hz]	Damping Ratio [/]	Residuum Magn.	Phase [deg]	Mode $\lvert\phi_{yn}\cdot\phi_{xn}/M_n\rvert$ [/]
1.65	2.60	1.90	0.0653	9.39E-04	11.2	2.21E-02
1.65	2.60	1.94	0.0654	1.06E-03	151.0	2.65E-02
1.65	2.60	2.50	-0.0068	3.81E-06	-28.7	1.19E-04
3.95	4.15	4.06	0.0409	1.55E-04	90.0	7.91E-03
4.40	4.70	4.55	0.0418	2.28E-04	90.0	1.31E-02
5.35	5.60	5.43	0.0439	2.09E-04	90.0	1.43E-02

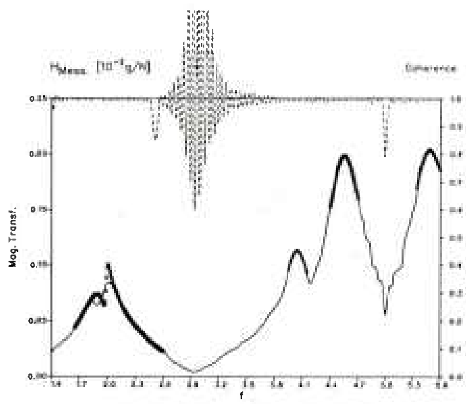
FIG. 4.3-3 INFLUENCE OF DEFINITION OF EXCITATION; WING; EXCITATION : LEFT



(r W, r ; z ; 0.032 × 4096 ; 30 p ; i 5)

Frequency Interval [Hz]		Haupt Freq. [Hz]	Damping Ratio [/]	Residuum Magn.	Phase [deg]	Mode $\lvert\phi_{yn}\cdot\phi_{xn}/M_n\rvert$ [/]
1.65	2.60	1.94	0.1339	7.74E-04	88.7	1.87E-02
1.65	2.60	2.02	0.0028	1.84E-05	166.1	4.67E-04
3.95	4.15	4.08	0.0359	1.13E-04	90.0	5.77E-03
4.40	4.70	4.56	0.0407	1.84E-04	90.0	1.05E-02
5.35	5.60	5.43	0.0550	2.98E-04	90.0	2.03E-02

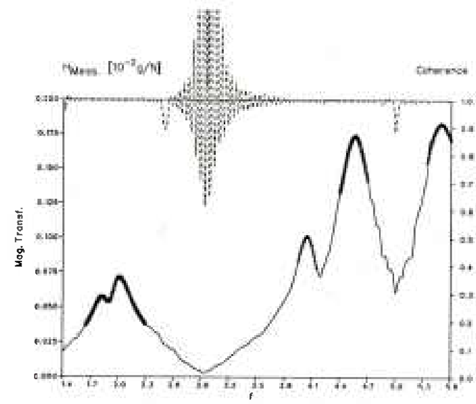
FIG. 4.3-4 EXCITATION: RIGHT; ANALYSED WITH 2 MODES IN FREQUENCY RANGE 1.65-2.60 Hz



(r W, l ; z ; 0.032 × 4096 ; 30 p ; i 5)

Frequency Interval [Hz]		Haupt Freq. [Hz]	Damping Ratio [/]	Residuum Magn.	Phase [deg]	Mode $\lvert\phi_{yn}\cdot\phi_{xn}/M_n\rvert$ [/]
1.65	2.60	1.99	0.0109	3.77E-05	169.6	9.44E-04
1.65	2.60	1.93	0.1149	7.89E-04	87.3	1.89E-02
3.95	4.15	4.06	0.0409	1.55E-04	90.0	7.91E-03
4.40	4.70	4.55	0.0418	2.28E-04	90.0	1.31E-02
5.35	5.60	5.43	0.0439	2.09E-04	90.0	1.43E-02

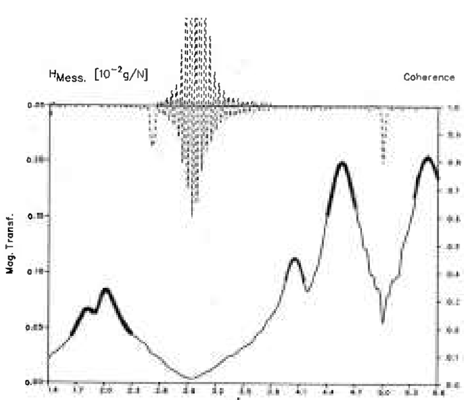
FIG. 4.3-5 EXCITATION : LEFT; ANALYSED WITH 2 MODES IN FREQUENCY RANGE 1.65-2.60 Hz



(r W, r ; z ; 0.032 × 4096 ; 30 p ; i 5)

Frequency Interval [Hz]		Haupt Freq. [Hz]	Damping Ratio [/]	Residuum Magn.	Phase [deg]	Mode $\lvert\phi_{yn}\cdot\phi_{xn}/M_n\rvert$ [/]
1.65	2.30	1.88	0.0607	3.76E-04	18.8	8.75E-03
1.65	2.30	1.97	0.0674	5.66E-04	129.0	1.44E-02
3.95	4.15	4.08	0.0359	1.13E-04	90.0	5.77E-03
4.40	4.70	4.56	0.0407	1.84E-04	90.0	1.05E-02
5.35	5.60	5.43	0.0550	2.98E-04	90.0	2.03E-02

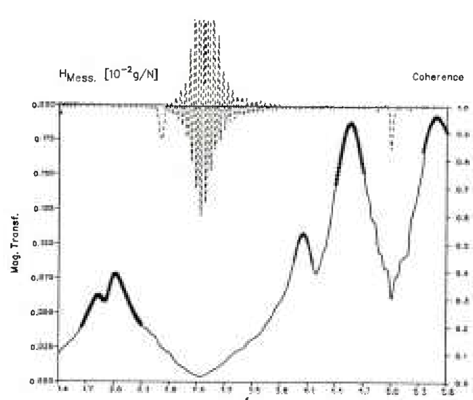
FIG. 4.3-6 EXCITATION : RIGHT; ANALYSED WITH 2 MODES IN FREQUENCY RANGE 1.65-2.30 Hz



(r W, l ; z ; 0.032 × 4096 ; 30p ; i5)

Frequency Interval [Hz]		Haupt Freq. [Hz]	Damping Ratio [/]	Residuum Magn.	Phase [deg]	Mode $\lvert\phi_{yn}\cdot\phi_{xn}/M_n\rvert$ [/]
1.65	2.30	1.85	0.0663	3.33E-04	54.2	7.49E-03
1.65	2.30	1.99	0.0611	3.94E-04	119.6	1.01E-02
3.95	4.15	4.06	0.0409	1.55E-04	90.0	7.91E-03
4.40	4.70	4.55	0.0418	2.28E-04	90.0	1.31E-02
5.35	5.60	5.43	0.0439	2.09E-04	90.0	1.43E-02

FIG. 4.3-7 EXCITATION: LEFT; ANALYSED WITH 2 MODES IN FREQUENCY RANGE 1.65-2.30 Hz



(r W, r + l ; z ; 0.032 × 4096 ; 30 p ; i 5)

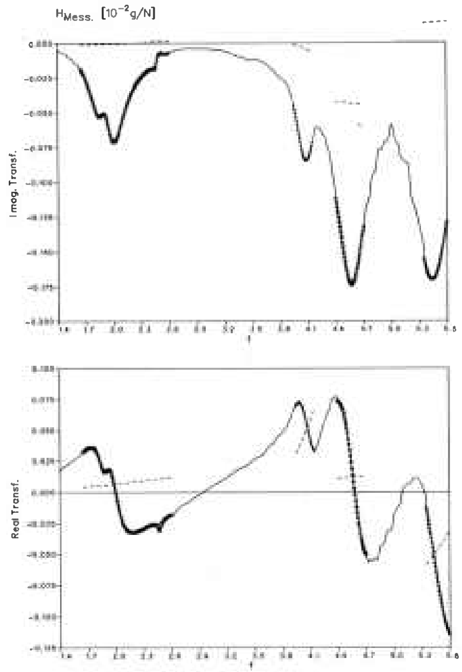
Frequency Interval [Hz]		Haupt Freq. [Hz]	Damping Ratio [/]	Residuum Magn.	Phase [deg]	Mode $\lvert\phi_{yn}\cdot\phi_{xn}/M_n\rvert$ [/]
1.65	2.30	1.88	0.0681	5.74E-04	31.9	1.32E-02
1.65	2.30	1.96	0.0623	5.86E-04	146.2	1.49E-02
3.95	4.15	4.07	0.0376	1.25E-04	90.0	6.38E-03
4.40	4.70	4.56	0.0441	2.41E-04	90.0	1.38E-02
5.35	5.60	5.39	0.0578	3.78E-04	90.0	2.54E-02

FIG. 4.3-8 EXCITATION: LEFT + RIGHT; ANALYSED WITH 2 MODES IN RANGE 1.65-2.3 Hz

RESP/EXC.		R/R	R/L	R/R	R/L	R/R	R/L	R/(R+L)	SCATTER
NO OF MODES		3	3	2	2	2	2	2	% OF
FREQU.RANGE		(1.65 ÷	2.60)	(1.65 ÷	2.60)	(1.65	÷	2.3)	"R/R;3"
									-/+
MODE:									
EY	FREQU.(HZ)	1.90	1.90			1.88	1.85	1.88	3/0
	DAMP. (%)	4.9	6.5			6.1	6.6	6.8	/39
1.WZ		1.95	1.94	1.94*	1.93*	1.97	1.99	1.96	1/2
		8.1	6.5	13.4	11.5	6.7	6.1	6.2	25/
AWZ		2.47	~~2.50*~~	2.02*	1.99*	* POOR, FITTING NOT			
		1.0	~~-0.7~~	0.3	1.1	INCLUDED IN SCATTER			
WX		4.08	4.06	S.L.	S.L.	S.L.	S.L.	4.07	1/
		3.6	4.1					3.8	/14
FZ		4.56	4.55	S.L.	S.L.	S.L.	S.L.	4.56	0/0
		4.1	4.2					4.4	/5
2.WZ		5.43	5.43	S.L.	S.L.	S.L.	S.L.	5.39	1/0
		5.5	4.4					5.8	20/5
								MAX.	3
									39

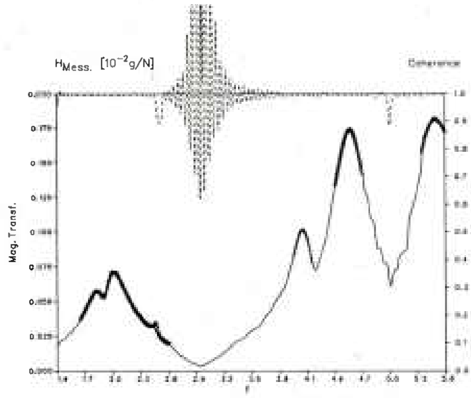
TABLE 4.3-1 INFLUENCE OF CHOSEN EXCITATION SIGNAL

(W ; z ; 0.032 × 4096 ; 30 p ; i 5)



(r W, r ; z ; 0.032 × 4096 ; 30p ; i 5)

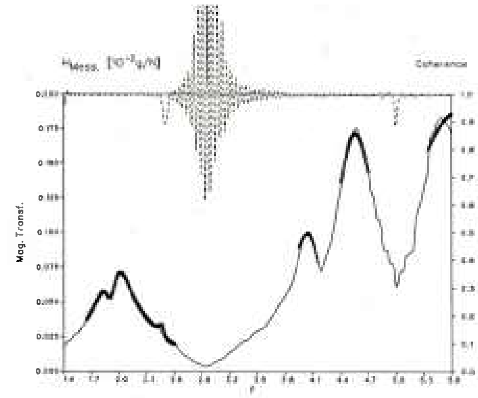
FIG. 4.4-1 REAL AND IMAGINARY PART OF TRANSFER FUNCTION OF ACCELERATION SHOWING OFF-SET CORRECTION



(r W, r; z; 0.032 × 4096; 30p; i3)

Frequency Interval [Hz]		Haupt Freq. [Hz]	Damping Ratio [/]	Residuum Magn.	Phase [deg]	Mode $\lvert\phi_{yn}\cdot\phi_{xn}/M_n\rvert$ [/]
1.65	2.60	1.90	0.0484	2.92E-04	-48.3	7.16E-03
1.65	2.60	1.95	0.0814	8.45E-04	103.7	2.10E-02
1.65	2.60	2.47	0.0095	5.50E-06	-2.3	1.71E-04
3.95	4.15	4.08	0.0359	1.13E-04	90.0	5.77E-03
4.40	4.70	4.56	0.0406	1.83E-04	90.0	1.05E-02
5.35	5.60	5.39	0.0574	3.51E-04	90.0	2.37E-02

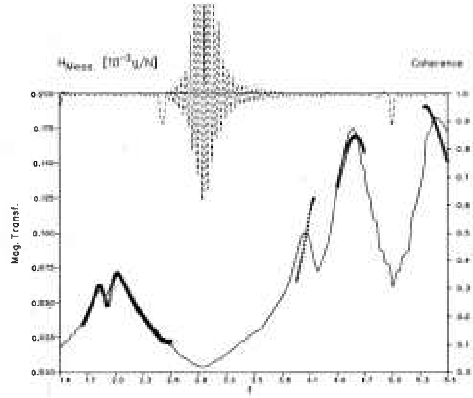
FIG. 4.4-2 INFLUENCE OF OFF-SET CORRECTION : 3 ITERATIONS



(r W, r; z; 0.032 × 4096; 30p; i1)

Frequency Interval [Hz]		Haupt Freq. [Hz]	Damping Ratio [/]	Residuum Magn.	Phase [deg]	Mode $\lvert\phi_{yn}\cdot\phi_{xn}/M_n\rvert$ [/]
1.65	2.60	1.91	0.0523	4.63E-04	-63.0	1.13E-02
1.65	2.60	1.94	0.0781	1.04E-03	102.1	2.56E-02
1.65	2.60	2.47	0.0113	6.26E-06	-9.4	1.95E-04
3.95	4.15	4.10	0.0467	1.69E-04	90.0	8.66E-03
4.40	4.70	4.56	0.0441	2.06E-04	90.0	1.18E-02
5.35	5.60	5.40	0.0894	6.11E-04	90.0	4.13E-02

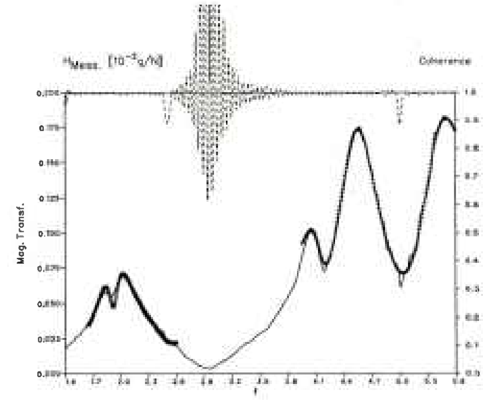
FIG. 4.4-3 INFLUENCE OF OFF-SET CORRECTION : 1 ITERATION



(r W, r; z; 0.032 × 4096; 30 p; 0)

Frequency Interval [Hz]		Haupt Freq. [Hz]	Damping Ratio [/]	Residuum Magn.	Phase [deg]	Mode $\lvert\phi_{yn}\cdot\phi_{xn}/M_n\rvert$ [/]
1.65	2.60	1.90	0.0455	4.54E-04	-37.7	1.11E-02
1.65	2.60	1.94	0.0706	9.38E-04	115.1	2.34E-02
1.65	2.60	2.50	-0.0692	4.10E-05	15.5	1.31E-03
3.95	4.15	4.16	0.0335	1.61E-04	90.0	8.38E-03
4.40	4.70	4.58	0.0570	3.36E-04	90.0	1.93E-02
5.35	5.60	5.34	0.0548	3.12E-04	90.0	2.09E-02

FIG. 4.4-4 INFLUENCE OF OFF-SET CORRECTION: 0 ITERATIONS (SOME: SINGLE MODE)



(r W, r; z; 0.032 × 4096; 30 p; 0)

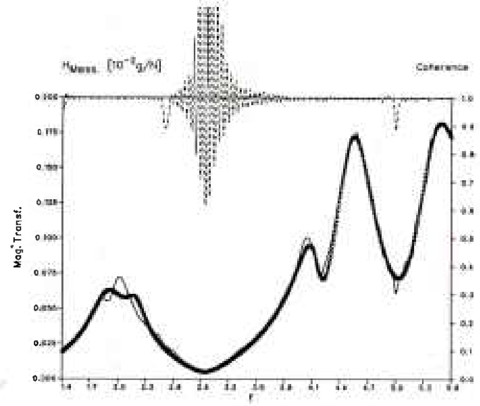
Frequency Interval [Hz]		Haupt Freq. [Hz]	Damping Ratio [/]	Residuum Magn.	Phase [deg]	Mode $\lvert\phi_{yn}\cdot\phi_{xn}/M_n\rvert$ [/]
1.65	2.60	1.90	0.0455	4.54E-04	-37.7	1.11E-02
1.65	2.60	1.94	0.0706	9.38E-04	115.1	2.34E-02
1.65	2.60	2.50	-0.0692	4.10E-05	15.5	1.31E-03
3.95	5.60	4.12	0.0344	8.96E-05	50.5	4.56E-03
3.95	5.60	4.55	0.0506	3.15E-04	93.7	1.80E-02
3.95	5.60	5.41	0.0478	2.20E-04	99.7	1.51E-02

FIG. 4.4-5 INFLUENCE OF OFF-SET CORRECTION: 0 ITERATIONS (ALL: MULTI MODE)

ITERATION		0	0	1	3	5	SCATTER % OF "5" -/+
MODE:		3;3	3;1	3;1	3;1	3;1	
EY	FREQU.(HZ)		1.90	1.91	1.90	1.90	0/1
	DAMP. (%)		4.6	5.2	4.8	4.9	6/6
1.WZ		S.R.	1.94	1.94	1.95	1.95	1/0
	*POOR FITTING,		7.1	7.8	8.1	8.1	12/0
	NOT INCLUDED						
AWZ	IN SCATTER	S.R.	~~2.50*~~	2.47	2.47	2.47	0/0
			~~-6.9~~	1.1	1.0	1.0	10/0
WX		4.12*	4.16*	4.10*	4.08	4.08	0
		3.4	3.4	4.7	3.6	3.6	0
FZ		4.55	4.58*	4.56	4.56	4.56	0/0
		5.1	5.7	4.4	4.1	4.1	0/24
2.WZ		5.41	5.34*	5.40*	5.39	5.43	1/
		4.8	5.5	8.9	5.7	5.5	13/4
						MAX.	1
							24

TABLE 4.4-1 INFLUENCE OF 'OFF-SET' CORRECTION

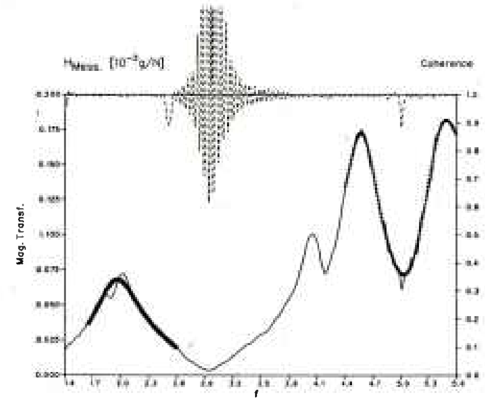
(r W, r; z; 0.032×4096; 30p)



(r W, r ; z ; 0.032 × 4096 ; 30 p ; i 5)

Frequency Interval [Hz]		Haupt Freq. [Hz]	Damping Ratio [/]	Residuum Magn.	Phase [deg]	Mode $\lvert\phi_{yn}\cdot\phi_{xn}/M_n\rvert$ [/]
1.40	5.60	1.90	0.1098	4.93E-04	93.0	1.18E-02
1.40	5.60	2.19	0.0559	1.14E-04	55.7	3.05E-03
1.40	5.60	4.13	0.0345	9.24E-05	55.3	4.72E-03
1.40	5.60	4.54	0.0473	2.91E-04	99.7	1.67E-02
1.40	5.60	5.41	0.0469	2.11E-04	101.4	1.44E-02

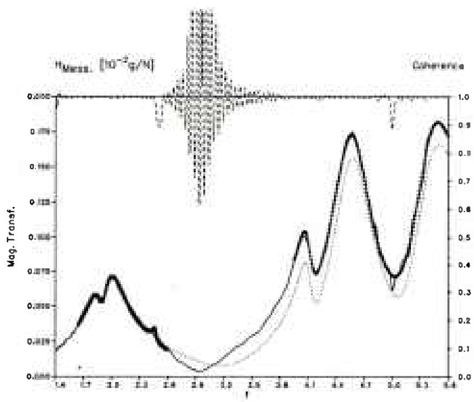
FIG. 4.5-1 INFLUENCE OF MODE NUMBER: 1 x (n = 5)



(r W, r ; z ; 0.032 × 4096 ; 30 p ; i 5)

Frequency Interval [Hz]		Haupt Freq. [Hz]	Damping Ratio [/]	Residuum Magn.	Phase [deg]	Mode $\lvert\phi_{yn}\cdot\phi_{xn}/M_n\rvert$ [/]
1.65	2.60	1.96	0.1244	7.09E-04	90.0	1.73E-02
4.40	5.60	4.58	0.0456	2.36E-04	82.1	1.35E-02
4.40	5.60	5.41	0.0456	1.97E-04	99.5	1.35E-02

FIG. 4.5-2 INFLUENCE OF MODE NUMBER: 1 x (n = 1) ; 1 x (n = 2)



(r W, r ; z ; 0.032 × 4096 ; 30 p ; i 5)

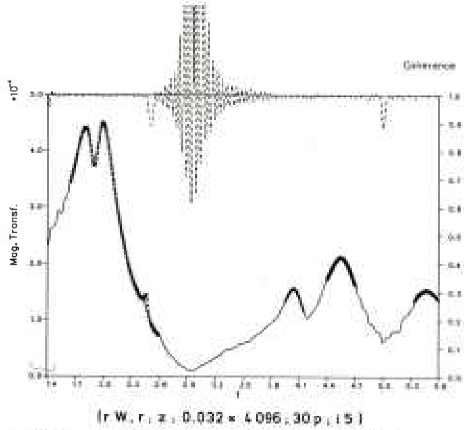
Frequency Interval [Hz]		Haupt Freq. [Hz]	Damping Ratio [/]	Residue Magn.	Phase [deg]	Mode $\lvert\phi_{yn}\cdot\phi_{xn}/M_n\rvert$ [/]
1.65	2.60	1.90	0.0490	2.82E-04	-36.6	6.89E-03
1.65	2.60	1.95	0.0807	8.04E-04	106.8	2.01E-02
1.65	2.60	2.47	0.0097	5.55E-06	0.8	1.72E-04
3.95	5.60	4.10	0.0205	4.20E-05	64.4	2.15E-03
3.95	5.60	4.57	0.0455	2.46E-04	85.8	1.41E-02
3.95	5.60	5.41	0.0449	1.89E-04	101.0	1.29E-02

FIG. 4.5-3 INFLUENCE OF MODE NUMBER : 2 x (n = 3)

NO OF MODES		5	1	2	3	SCATTER % OF "3" -/+
MODE:						
EY	FREQU.(HZ)				1.90	
	DAMP. (%)				4.9	
1.WZ		1.90*	1.96*	1.94*	1.95	* POOR FITTING, NOT INCLUDED IN SCATTER
		11.0	12.4	13.4	8.1	
AWZ		2.19*		2.02*	2.47	
		5.6		0.3	1.0	
WX		4.13*	4.08		4.10	1/
		3.5	3.6		2.1	/71
FZ		4.54	4.56	4.58	4.57	0/0
		4.7	4.1	4.6	4.6	11/2
2.WZ		5.41	5.43	5.41	5.41	0/0
		4.7	5.5	4.6	4.5	/22
					MAX.	1
						71

TABLE 4.5-1 INFLUENCE OF MODE NUMBER IN ANALYSIS

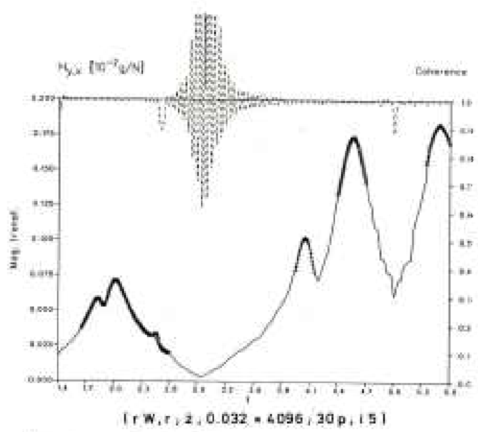
(r W, r ; z ; 0.032 × 4096 ; 30 p ; i 5)



(r W, r; z; 0.032 × 4096; 30 p; i 5)

Frequency Interval [Hz]		Haupt Freq. [Hz]	Damping Ratio [/]	Residuum Magn.	Phase [deg]	Mode [/]
1.65	2.60	1.90	0.0490	2.82E-04	-36.6	6.89E-03
1.65	2.60	1.95	0.0807	8.04E-04	106.8	2.01E-02
1.65	2.60	2.47	0.0097	5.55E-06	0.8	1.72E-04
3.95	4.15	4.08	0.0359	1.13E-04	90.0	5.77E-03
4.40	4.70	4.56	0.0407	1.84E-04	90.0	1.05E-02
5.35	5.60	5.43	0.0550	2.98E-04	90.0	2.03E-02

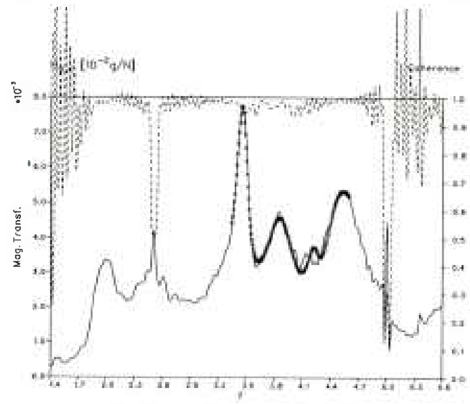
FIG. 4.6-1 TRANSFER FUNCTION: WING DEFORMATION AS A BASIS FOR APPROXIMATION



(r W, r; z̈; 0.032 × 4096; 30 p; i 5)

Frequency Interval [Hz]		Haupt Freq. [Hz]	Damping Ratio [/]
1.65	2.60	1.87	0.0462
1.65	2.60	1.98	0.0747
1.65	2.60	2.48	0.0116
3.95	4.15	4.08	0.0373
4.40	4.70	4.56	0.0418
5.35	5.60	5.44	0.0470

FIG. 4.6-2 TRANSFER FUNCTION: WING ACCELERATION AS A BASIS FOR APPROXIMATION



(r E, r; z̈; 0.032 × 4096; 30 p; i 5)

Frequency Interval [Hz]		Haupt Freq. [Hz]
3.35	4.60	3.88
3.35	4.60	4.24
3.35	4.60	4.46
3.35	4.60	3.46

FIG. 4.6-3 TRANSFER FUNCTION: ENGINE ACCELERATION AS A BASIS FOR APPROXIMATION

PICK UP ANALYSED / MODE:		WING Z	WING Z̈	ENGINE Z	ENGINE Z̈	MEAN OF Z/Z̈	SCATTER % OF MEAN -/+
EY	FERQU.(HZ)	1.90	1.87			1.89	2
	DAMP. (%)	4.9	4.6			4.8	3
1.WZ		1.95	1.98			1.97	1
		8.1	7.5			7.8	4
A WZ		2.47	2.48			2.47	1
		1.0	1.2			1.1	9
EZ				3.46	3.46	3.46	0
				1.7	1.7	1.7	0
AEZ				3.87	3.88	3.87	0
				4.4	4.4	4.4	0
WX		4.08	4.08	4.19	4.24 *	4.08	0
		3.6	3.7	1.9	1.9	3.6	0
FZ		4.56	4.56	4.46	4.46	4.56	0
		4.1	4.2	4.9	5.0	4.1	0
2.WZ		5.43	5.44			5.43	0
		5.5	4.7			5.1	8
						MAX.	2
							9

* NOT INCLUDED IN MEAN AND SCATTER

TABLE 4.6-1 COMPARISON OF ANALYSES OF ACCELERATION AND DEFORMATION

(r, r; 0.032 × 4096; 30 p; i 5)

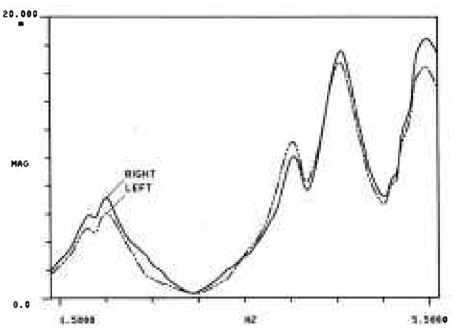


FIG. 4.7-1 A/C SYMMETRY: TRANSFER FUNCTIONS OF RIGHT AND LEFT WING

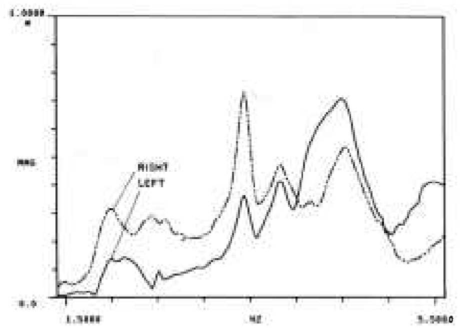
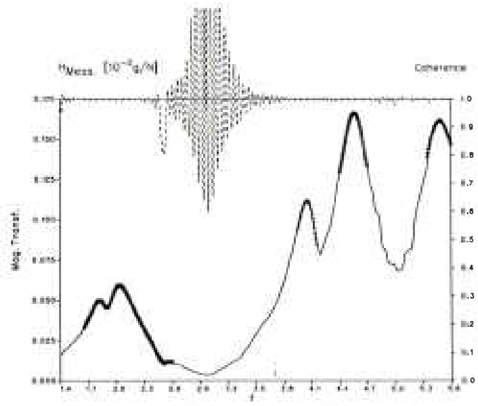


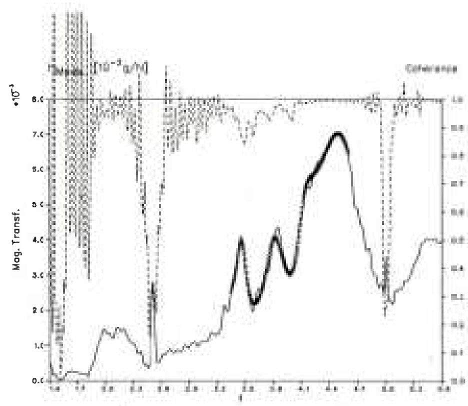
FIG. 4.7-3 A/C SYMMETRY: TRANSFER FUNCTIONS OF RIGHT AND LEFT ENGINE



(I W, r; z; 0.032 × 4096; 30p; i5)

Frequency Interval [Hz]		Haupt Freq. [Hz]	Damping Ratio [/]	Residuum Magn.	Phase [deg]	Mode $\|\phi_{yn} \cdot \phi_{xn} / M_n\|$ [/]
1.65	2.60	1.87	0.0560	2.11E-04	15.7	4.89E-03
1.65	2.60	1.99	0.0860	5.66E-04	108.8	1.45E-02
1.65	2.60	2.50	0.0382	2.09E-05	-174.0	6.53E-04
3.95	4.15	4.10	0.0400	1.69E-04	90.0	8.70E-03
4.40	4.70	4.56	0.0414	1.82E-04	90.0	1.04E-02
5.35	5.60	5.42	0.0537	2.84E-04	90.0	1.93E-02

FIG. 4.7-2 TRANSFER FUNCTION: LEFT WING



(I E, r; z; 0.032 × 4096; 30p; i5)

Frequency Interval [Hz]		Haupt Freq. [Hz]	Damping Ratio [/]	Residuum Magn.	Phase [deg]	Mode $\|\phi_{yn} \cdot \phi_{xn} / M_n\|$ [/]
3.35	4.60	3.82	0.0259	3.12E-06	-153.5	1.48E-04
3.35	4.60	4.11	0.0238	2.29E-06	-132.8	1.17E-04
3.35	4.60	4.53	0.0562	1.30E-05	79.3	7.33E-04
3.35	4.60	3.48	0.0168	4.46E-06	64.4	1.93E-04

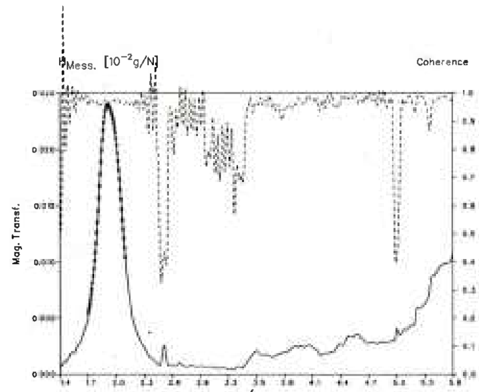
FIG. 4.7-4 TRANSFER FUNCTION: LEFT ENGINE

PICK UP LOCATION		WING		ENGINE		MEAN OF R/L	SCATTER % OF MEAN -/+
		RIGHT	LEFT	RIGHT	LEFT		
MODE:							
EY	FERQU.(HZ)	1.90	1.87			1.89	1
	DAMP. (%)	4.9	5.6			5.3	7
1.WZ		1.95	1.99			1.97	1
		8.1	8.6			8.4	3
A WZ		2.47	2.50			2.49	1
		1.0	3.8			2.4	58
EZ				3.46	3.48	3.47	0
				1.7	1.7	1.7	0
AEZ				3.87	3.82	3.85	1
				4.4	2.6	3.5	26
WX		4.08	4.10	4.19	4.11 *	4.09	0
		3.6	4.0	1.9	2.4	3.8	5
FZ		4.56	4.56	4.46	4.53	4.56	0
		4.1	4.1	4.9	5.6	4.1	0
2.WZ		5.43	5.42			5.43	0
		5.5	5.4			5.4	0

							1
						MAX.	58(7)

* NOT INCLUDED IN MEAN AND SCATTER

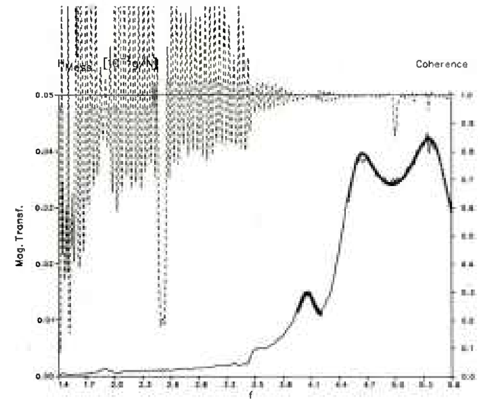
TABLE 4.7-1 MODAL DATA FROM SYMMETRICAL PICK - UPS (-, r; z; 0.032 × 4096; 30p; i5)



(r E , r ; y ; 0.032 × 4096 ; 30 p ; i 5)

Frequency Interval [Hz]		Haupt Freq. [Hz]	Damping Ratio [/]	Residuum Magn.	Phase [deg]	Mode $\|\phi_{yn} \cdot \phi_{xn} / M_n\|$ [/]
1.70	2.10	1.86	0.0466	1.05E-04	56.4	2.39E-03
1.70	2.10	2.02	0.0517	9.50E-05	-127.5	2.35E-03

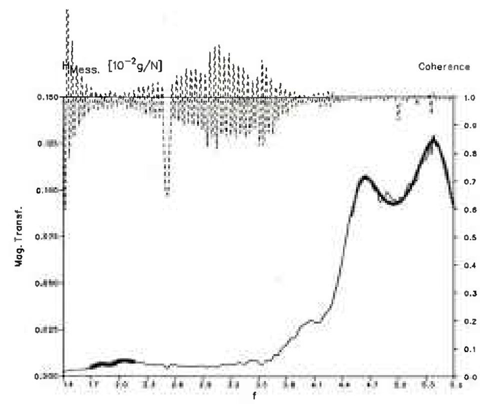
FIG. 4.8-1 TRANSFER FUNCTION : ENGINE, LATERAL



(F ; r ; z ; 0.032 × 4096 ; 30 p ; i 5)

Frequency Interval [Hz]		Haupt Freq. [Hz]	Damping Ratio [/]	Residuum Magn.	Phase [deg]	Mode $\|\phi_{yn} \cdot \phi_{xn} / M_n\|$ [/]
3.95	4.20	4.07	0.0261	8.45E-06	90.0	4.32E-04
4.50	5.60	4.57	0.0424	4.98E-05	87.8	2.86E-03
4.50	5.60	5.43	0.0451	5.35E-05	-92.0	3.64E-03

FIG. 4.8-2 TRANSFER FUNCTION : FRONT FUSELAGE



(H ; r ; z ; 0.032 × 4096 ; 30 p ; i 5)

Frequency Interval [Hz]		Haupt Freq. [Hz]	Damping Ratio [/]	Residuum Magn.	Phase [deg]	Mode $\|\phi_{yn} \cdot \phi_{xn} / M_n\|$ [/]
1.70	2.15	1.86	0.0581	3.10E-05	-158.7	7.10E-04
1.70	2.15	1.98	0.0865	7.80E-05	-68.3	1.99E-03
4.50	5.60	4.58	0.0450	1.57E-04	72.8	8.81E-03
4.50	5.60	5.42	0.0431	1.53E-04	-107.7	1.03E-02

FIG. 4.8-3 TRANSFER FUNCTION : TIP OF HORIZONTAL TAIL

PICK UP LOCATION MODE:		RW	LW	REZ	LEZ	REY	F	H	MEAN	SCATTER % OF MEAN -/+
EY	FREQU.(HZ)	1.90	1.87			1.86		1.86	1.88	1/1
	DAMP. (%)	4.9	5.6			4.7		5.8	5.1	8/14
1.WZ		1.95	1.99			2.02		1.98	1.99	2/2
		8.1	8.6			5.2		8.7	7.7	32/13
A WZ		2.47	2.50						2.49	1/0
		1.0	3.8						2.4	58/58
EZ				3.46	3.48				3.47	0/0
				1.7	1.7				1.7	0/0
A EZ				3.87	3.82				3.85	1/1
				4.4	2.6				3.5	26/26
WX		4.08	4.10	4.19	4.11		4.07		4.11	1/2
		3.6	4.0	1.9	2.4		2.6		2.9	34/38
FZ		4.56	4.56	4.46	4.53		4.57	4.58	4.54	0/1
		4.1	4.1	4.9	5.6		4.2	4.5	4.6	11/22
2.WZ		5.43	5.42				5.43	5.42	5.43	0/0
		5.5	5.4				4.5	4.3	4.9	12/12

										2
									MAX.	58(38)

TABLE 4.8-1 INFLUENCE OF LOCATION

(-, r ; 0.032 × 4096 ; 30 p ; i 5)

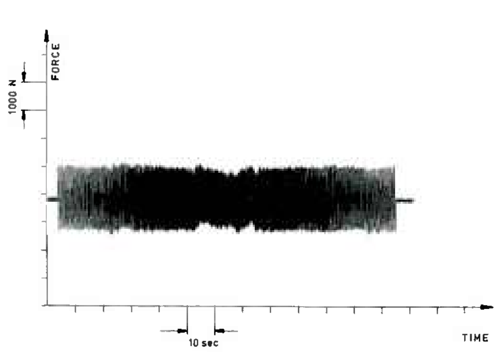


FIG. 4.9-1 LIFT FORCE

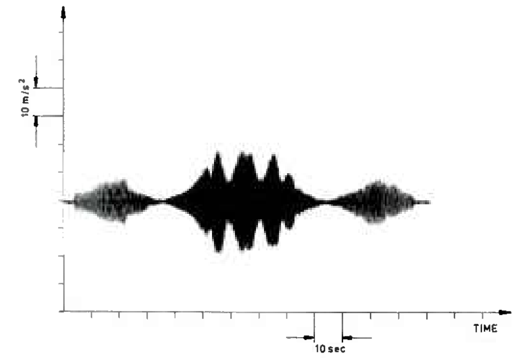
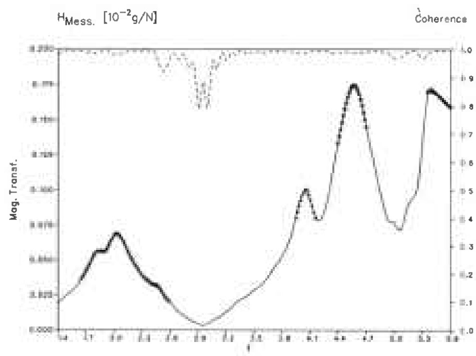


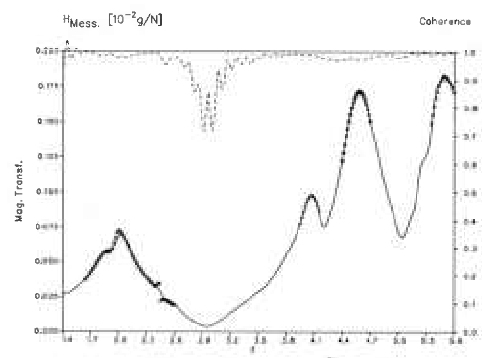
FIG. 4.9-2 WING TIP ACCELERATION



(r W , r ; z ; 0.032 × 2048 ; 30 p ; i 5)

Frequency Interval [Hz]		Haupt Freq. [Hz]	Damping Ratio [/]	Residuum Magn.	Phase [deg]	Mode $\|\phi_{yn}\cdot\phi_{xn}/M_n\|$ [/]
1.65	2.60	1.87	0.0656	2.55E-04	37.7	5.81E-03
1.65	2.60	1.99	0.0763	4.73E-04	116.7	1.22E-02
1.65	2.60	2.48	0.0261	9.93E-06	4.8	3.09E-04
3.95	4.15	4.08	0.0321	8.68E-05	90.0	4.45E-03
4.40	4.70	4.57	0.0434	2.13E-04	90.0	1.22E-02
5.35	5.60	5.29	0.0591	3.52E-04	90.0	2.34E-02

FIG. 4.9-3 ANALYSIS OF FIRST HALF OF SWEEP



(r W , r ; z ; 0.032 × 2048 ; 30 p ; i 5)

Frequency Interval [Hz]		Haupt Freq. [Hz]	Damping Ratio [/]	Residuum Magn.	Phase [deg]	Mode $\|\phi_{yn}\cdot\phi_{xn}/M_n\|$ [/]
1.65	2.60	1.96	0.0319	5.87E-05	-159.9	1.67E-03
1.65	2.60	1.94	0.1117	5.56E-04	84.5	1.57E-02
1.65	2.60	2.44	0.0024	2.44E-06	-50.9	7.49E-05
3.95	4.15	4.09	0.0390	1.03E-04	90.0	5.29E-03
4.40	4.70	4.57	0.0483	2.62E-04	90.0	1.50E-02
5.35	5.60	5.44	0.0375	1.22E-04	90.0	8.30E-03

FIG. 4.9-4 ANALYSIS OF SECOND HALF OF SWEEP

SIGNAL LENGTH		1. HALF	2. HALF	COMPLET	SCATTER % OF COMPLET -/+
MODE:					
EY	FREQU.(HZ)	1.87	1.94	1.90	2/2
	DAMP. (%)	6.6	11.2	4.9	/129
1.WZ		1.99	1.96	1.95	/2
		7.6	3.2	8.1	60/
A WZ		2.48	2.44*	2.47	/0
		2.6	0.2	1.0	/160
	* POOR FITTING NOT INCLUDED IN SCATTER				
WX		4.08	4.09	4.08	0/0
		3.2	3.9	3.6	11/8
FZ		4.57	4.57	4.56	/0
		4.3	4.8	4.1	/17
2.WZ		5.29	5.44	5.43	3/0
		5.9	3.8	5.5	31/7

					3
					160(129)

TABLE 4.9-1 INFLUENCE OF EXTERNAL DISTURBANCES

(r W , r ; z ; 0.032 × - ; 30 p ; i 5)

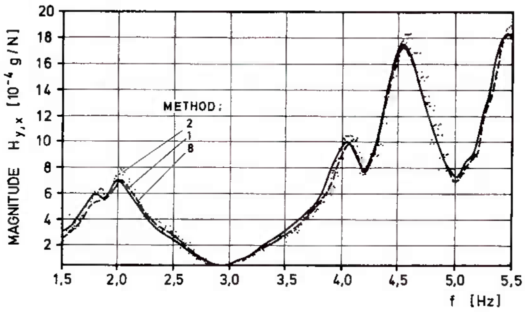


FIG. 4.10-1 DIFFERENT TRANSFER FUNCTIONS OF WING FROM DIFFERENT ANALYSIS OF THE SAME DATA

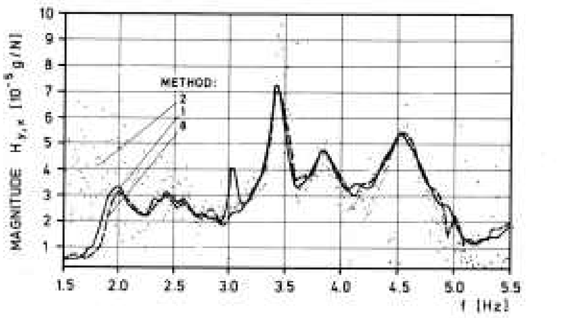


FIG. 4.10-2 DIFFERENT TRANSFER FUNCTIONS OF ENGINE FROM DIFFERENT ANALYSIS OF THE SAME DATA

METHOD ANALY. P. UP	8 Z RW	8 Z RW	8 Z LW	8 Z RE	8 Z RE	8 Z LE	8 Y RE	8 Z F	8 Z H	2 / RW	2 / RE (Z)	1 / RW	1 / RE (Z)	MEAN OF UNDER- LINED	SCATTER % OF MEAN -/+
MODE:															
EY	1.90 4.9	1.87 4.6	1.87 5.6	FREQU.(HZ) DAMP. (%)			1.86 4.7		1.86 5.8	1.75 *		1.74 *8.5		1.86 4.7	/2 2/32
1.WZ	<u>1.95</u> 8.1	<u>1.98</u> 7.5	<u>1.99</u> 8.6				2.02 5.2		1.98 8.7	<u>2.03</u> *		<u>2.02</u> 7.9		1.99 8.0	2/2 35/9
A WZ	2.47 *1.0	2.48 *1.2	2.50 3.8			* POOR FIITING, NOT INCLUDED IN SCATTER									
EZ				<u>3.46</u> 1.7	<u>3.46</u> 1.7	<u>3.48</u> 1.7					<u>3.47</u> 1.2		<u>3.45</u> 2.1	3.46 1.7	0/1 29/24
A EZ				3.87 4.4	3.88 4.4	3.82 2.6					3.83 *		3.90 4.2		
WX	4.10 2.1	4.08 3.7	4.10 4.0	4.19 1.9	4.24 *1.9	4.11 2.4		4.07 2.6		4.07 2.4	4.12 *	4.03 2.1			
FZ	4.57 4.6	4.56 4.2	4.56 4.1	4.46 4.9	4.46 5.0	4.53 5.6		<u>4.57</u> 4.2	<u>4.58</u> 4.5	4.56 4.4	4.54 *	4.55 4.1	4.54 4.4	4.57 4.4	2/0 7/27
2.WZ	<u>5.41</u> 4.5	<u>5.44</u> 4.7	<u>5.42</u> 5.4					5.43 4.5	5.42 4.3			5.43 4.4		5.41 4.5	/0 4/20 ---- 2
														MAX.	35

TABLE 4.10-1 COMPARISON OF BEST AVAILABLE DATA FROM DIFFERENT SOURCES

(METHOD 8 : - , r ; 0.032 × 4096 ; 30 p ; i5)

INFLUENCE	FREQUENCY (%)	DAMPING (%)
	OF MOST RELIABLE	
METHOD	5	45
DIGITISATION	1	24
CORRELAT.LENGTH (30%)	1	80
EXCITATION	3	39
ITERATION	1	24
NO. OF MODES	1	71
DEFORM. OR ACCEL.	2	9
SYMETR. LOCATION	1	58 (7)
LOCATION	2	58 (38)
EXT. DISTURBANCE	3	160 (129)
BEST AVAILABLE	2	35

TABLE 5-1 ACCURACY OF MODAL DATA DUE TO DIFFERENT INFLUENCES

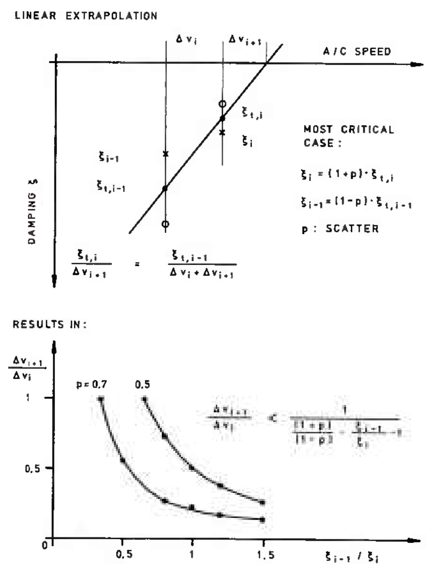


FIG. 5-1 ALLOWABLE SPEED INCREASE

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"Flight Vibration Test Analysis-Methods, Theory and Application"
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REPORT DOCUMENTATION PAGE			
1. Recipient's Reference	2. Originator's Reference AGARD-R-720	3. Further Reference ISBN 92-835-1470-X	4. Security Classification of Document UNCLASSIFIED
5. Originator	Advisory Group for Aerospace Research and Development North Atlantic Treaty Organization 7 rue Ancelle, 92200 Neuilly sur Seine, France		
6. Title	PROBLEMS OF SYSTEM IDENTIFICATION IN FLIGHT VIBRATION TESTING		
7. Presented at	the 57th Meeting of the Structures and Materials Panel held in Vimeiro, Portugal on 9–14 October 1983.		
8. Author(s)/Editor(s) K.Koenig			9. Date April 1984
10. Author's/Editor's Address MBB GmbH UT & V Postfach 10 78 45 2800 Bremen 1, Germany			11. Pages 26
12. Distribution Statement	This document is distributed in accordance with AGARD policies and regulations, which are outlined on the Outside Back Covers of all AGARD publications.		
13. Keywords/Descriptors	Aircraft Airframe Vibration	Flight tests Vibration tests	

14. Abstract

This paper was presented to the Aeroelasticity Sub-Committee of the Structures and Materials Panel. It describes some "state of the art" experiments which were made for system identification in the course of flight vibration tests on a modern airliner. Data was reduced using proprietary modal analysers and a more general method developed by the author for use on a digital computer. The influence of external disturbances such as air turbulence on the modal forcing is considered. A comparison of the results for modal frequencies and damping ratios shows considerable variation in accuracy as between the different approaches.

It is concluded that the present state-of-the-art is poor and puts forward some ways in which improvements could be realized.

AGARD Report No.720
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